U.S. Department of Transportation
Federal Aviation Administration

Aeromedical Research Resume
Research Project Description Subtask for FY00

1. Title:	**2. Sponsoring Organization/Focal Point (FP)**	**3. Originator Name, Organization, Phone : AAM-510 (405) 954-6828**
General Aviation Human Factors Research Program: Advanced flight-deck technology	AIR-3; N. Lane AAM-1; J. Jordan, M.D. ACE-110; M. Dahl AFS-400; R. Wright AFS-800; M. Henry AAR-100; R. Simmons	Dennis B. Beringer, Ph.D. Kevin W. Williams, Ph.D. Thomas E. Nesthus, Ph. D. Kurt Joseph, M.S.
		4. Origination Date: July 1999
5. Parent RPI Number: Flight Deck Human Factors	**6. Subtask Number:** AM-A-00-HRR-519	**7. Completion Date:** September 2002
8. Parent MNS: 187	**9. RPI Manager Name, Organization, Phone:** David J. Schroeder, Ph.D. AAM-500, FAA Civil Aeromedical Institute (405) 954-6825	

10. Research Objective(s):

This ARR details a plan for the conduct of human factors research in response to regulation and certification (AVR) requirements. Additionally, this ARR supports the objectives of AAR-100's GA human factors program. A primary objective is to develop and test interventions, which will mitigate or eliminate root causes of general aviation pilot "errors" and thereby achieve a reduction in general aviation accidents and incidents. Human factors information and data gained via that objective will provide a sound scientific basis for the FAA and the GA Industry Coalition to develop and execute certification and rule making initiatives which will result in gains in general aviation safety. Specifically, the research is designed to: (1) investigate the impact of advanced, high-technology equipment in GA cockpit system designs on pilot performance, (2) assess the impact of various human factors variables on pilot performance under specified flight regimes; (3) identify aircraft system designs and environments which tend to induce errors and degrade pilot performance as well as develop pilot/aircraft interface design guidelines; (4) support standards and certification efforts by collecting empirical pilot performance data upon which to base regulatory and aircraft systems certification decisions concerning these aircraft systems; and (5) provide support for developing advisory circulars and other informational materials for educational purposes. (Joint FAA-NASA programs: Advanced General Aviation Transport Experiments (AGATE), Aviation Weather Information (AWIN), Small Airplane Transportation System (SATS).)

11. Technical Summary:

This ARR includes a multi-task approach to meeting the research objectives noted above. For the most part, these tasks will involve laboratory research and simulation to investigate specific factors and conditions, which are felt to impact GA pilot performance. The primary research tools in conducting this research will be CAMI's two GA flight simulators: the Advanced General Aviation Research Simulator (AGARS) and the Basic General Aviation Research Simulator (BGARS). Research protocols, scenarios, and flight regimes will be configured to emulate the flight environment critical to the human factors research question under study. Recommendations will be provided based on empirical pilot performance data obtained from high-fidelity real-time simulation. Wherever appropriate, pilot-subject response data will be presented in the form of probability functions, performance curves, and other graphic and probabilistic data presentations, which will support Agency actions. Human engineering design recommendations will be offered, based on study results, which may serve to improve the pilot-aircraft system interface, mitigate pilot error, and enhance flight safety.

12. Resources Requirements: FY-00 FY-01 FY-02

FAA Staff Years	6.0	6.0	6.0

13. Description of Work:

(1) Brief Background

This ARR has components dating to FY'94, which began with an investigation of performance enhancements attainable through the use of an integrated horizontal situation indicator (HSI) in place of separated non-integrated instrumentation (directional gyro and VOR head). During the course of that ARR, numerous investigations documenting pilot performance findings were conducted. This ARR is an outgrowth and extension of those efforts. Contributions continue to be made to the development of certification criteria for autopilot / autotrim autonav systems, providing inputs on the flight work package for AGATE, the examination of criteria for airborne primary and multi-function displays, defining design criteria for HUDs, and the documentation of pilot hearing thresholds and auditory warning criteria. Continuing support (system development and testing & evaluation) for the AGATE program and the follow-on SATS program, as well as the NASA-sponsored AWIN program, is provided within the tasks that comprise this ARR.

(2) Statement of Work

This is a multiple-task ARR and includes tasks with several component phases or stages dependent upon the success of earlier efforts. Components of tasks that were completed as part of a previous ARR are noted.

<u>General Hypothesis</u>: that the cockpit flight systems innovations designed and/or tested will produce statistically significant gains in one or more measures of pilot performance and contribute significantly to value-added assessments.

Task 1 - Pilot visual performance with integrated Primary Flight Displays (PFDs).

This ongoing task is in response to several lines of inquiry, all relating to pilot performance when using integrated Primary Flight Displays. A primary thrust is the continuing support of the highway-in-the-sky evaluations being conducted in support of AGATE, and in the development of recommended certification criteria for these displays. This is an interactive task with multiple phases that are pre-designed in response to the evolving requirements of AGATE as those needs arise and to the developing needs of the Aircraft Certification Service (AIR). AIR has already received its first request for certification of a highway-in-the-sky (HITS) format PFD, and this task is intended to support Certification in the evaluation of this and future applications. Primary Flight Displays may be presented either on head-down (on the instrument panel) or on head-up displays, the latter now being available for GA aircraft and already installed in aircraft like the King Air, Cessna Citation, and Gulfstream. Installation is also envisioned for AGATE/SATS aircraft when the devices achieve a cost that makes them viable for mid-level GA aircraft. AGATE involvement is through working group 4.1, primary flight displays.

Three types of concerns are present for these displays. First, there is interest in the effective field of view within the GA cockpit and where it is allowable to place head-down displays. The functional field of view literature needs updating to produce usable limits (for certification) for the placement of both PFDs and MFDs. Second, HITS-format displays are thought to be quite compelling, and there is concern that pilots may spend too much time fixated upon this particular PFD to the exclusion of other instrumentation and out-the-window scanning. Third, head-up displays have been suggested as a means of reducing the proportion of time that the pilot spends head-down, but some devices have appeared on the market that are noncollimated, meaning that they present images at a near focal distance rather than at optical infinity.

This has been demonstrated to disrupt visual surveillance at distances where aircraft targets are likely to be in the out-the-window scene by affecting both clarity and perceived size/location of visual targets. Beyond the HUD, devices are now becoming available that may supplant the HUD and allow unrestricted access to overlaid synthetic imagery throughout the pilot's visual field. These head-mounted see-through display systems will additionally present their own unique problems in terms of contrast, hysteresis (display lag), and cognitive and perceptual capture. Concerns have also been voiced relative to operational problems in rotorcraft when using night-vision goggles, with some of the perceptual problems being common to these and other imaging devices.

The activities to be performed in assessing the impacts of these technologies will include (1) conducting task analyses wherein candidate tasks for PFD (HDD or HUD) implementation are identified for further experimental examination and (2) assessing the impact of both collimated HUDs, noncollimated HUDs and head-down presentations on visual scan patterns and target detection. First, it is important that a determination of GA flight tasks that can be aided by these display formats be completed. Some tasks are likely to benefit more from graphical perspective presentation of data than do others. For example, maintaining cruise altitude may not be as germane a task for PFD use as would flying an approach. It is also important to determine if there are tasks that are performed in VMC that can benefit from an integrated PFD presentation, particularly if this presentation allows the pilot to perform the tasks with less effort/training and to conduct surveillance of surrounding airspace more effectively. Examination of the human factors issues relevant to the certification issues will use pilot subjects performing full-mission scenarios. These scenarios will contain flight tasks selected from the task analyses that represent tasks most likely and least likely to benefit from a HUD presentation. Comparative analyses will be used to determine if any substantial degradation in visual search is concurrent with the presence and/or use of the HUD/HDD and which of the selected tasks benefit most from an each type of presentation. This task was initiated in a previous ARR in FY'98 and will continue into 2001.

Task 2 - Multi-function Display (MFD) guidelines, standards, and evaluation procedures.

The avionics market is now replete with multi-function units offering a variety of functions, not necessarily standardized upon any common set of human factors criteria. The appearance of these devices, while a significant aid to navigation and flight planning, has produced several concerns. Those that are not integrated into the aircraft panel in a meaningful fashion have the potential of distracting pilot attention and disrupting the pilot's visual scan, particularly if the display is used for momentary guidance (course tracking). Additionally, the small low-contrast displays seen on some units are difficult to read at normal cockpit viewing distances, when presenting moving map displays. In a number of cases it is evident that engineering conveniences have been design determiners rather than the application of fundamental human factors principles. The structure of the software interface is also of concern, particularly where the menu structure is such that it complicates "navigation" through the control hierarchy of the unit. This task is designed to examine to what degree established human factors principles are being applied to these MFD-operator interfaces and to define any additional or specific guidelines applicable to the design and use of such systems.

This task has two components. The first subtask is largely completed and involved the compilation of both an annotated bibliography and a summary of guidelines and standards for the design and use of MFDs. The products from this subtask are being used to assist in the formation of a coherent set of criteria for evaluating the efficacy and safety of MFDs, and this effort will continue into FY2000. The second subtask involves the provision of guidelines, standards, and certification criteria for the AGATE MFD/PFD as well as simulator-based performance evaluations of candidate configurations. This investigation is presently using actual representative MFD units, developed both for AGATE and for commercial sale, as well as simulated MFDs interfaced to and driven by the BGARS and the AGARS for the initial evaluation of displays, control interfaces, and menu structures.

This will be accomplished by examination of an integrated MFD modifiable by the experimenter within which key parameters will be examined relating to MFD characteristics and control interface structure. Continuing experimentation will focus on issues of display integration (overlays, prioritization, formatting), minimum functional requirements, and interface standardization. Interfacing with AGATE/SATS is through working groups 4.3 (multi-function displays, weather/traffic), 4.4 (navigation displays) and 4.5 (interface devices; CAMI is lead). Other interfacing with NASA is through AWIN, and will involve continuing iterative support. Deliverables from this task are also being provided to SAE G-10 (subcommittee on MFDs) in support of preparation of both an ARP and ARD.

Additional support for this task is through two research grants. The New Mexico State University is providing baseline analytical data on present cockpit information requirements and those anticipated for the "free flight" environment ("The source, priority, and organization of elements of information accessed by pilots in various in-flight emergencies") as an aid in developing cockpit displays, communications requirements, and datalink parameters. These results will also aid in the performance of Task 3 discussed below. The University of Illinois at Urbana-Champaign is providing empirical data on baseline pilot performance for IMC and VMC pilotage for comparison with augmented data sources, displays, and means of pilot self-determination of routing. The investigation will also examine the effects of data reliability on pilot resolution of conflicts. Development of the annotated bibliography and guidelines summary was supported by Monterey Technologies, Inc., as a contractor.

Task 3 - Cockpit Auditory and Visual Alarms in a multi-task environment.

Each technological innovation installed in the aircraft cockpit with an alarm or warning mode requires a thorough understanding of how a flight crewmember will interface with the system being guarded. This information is important to the FAA in fulfilling its responsibility for certification. Although standard human factors principles can be applied in these instances, such standards are often inadequate for complex interface design situations, particularly in a multi-task environment. Hence, pilot-aircraft interface design standards need to be developed and tested under a variety of operating circumstances. This project contributes to the development of standards through simulation studies and tests under realistic flight protocols and through the assessment of baseline hearing abilities in pilots and nonpilots, in both quiet and engine-noise environments (this baseline data collection was completed in FY ’99; additional data will be collected as needed to complete the population profile). This project was focused initially on alarms and malfunction warning systems for autopilot/autotrim systems and de-icing malfunction warning mechanisms. Present concerns involve the design of aural/visual signals for (a) data-link uplink in which sender and level of urgency (L-N-H) must be coded; and (b) pilot alerts to prevent controlled-flight-into-terrain (CFIT). Results will provide baseline performance data for developing standards to support certification of new cockpit systems.

Task 4 – Flight Systems Development for AGATE: Integration of Controls and Displays

The focus of the AGATE is to bring advanced technology into the general aviation cockpit with the goals of enabling all-weather autonomous operations, improving pilots' situational awareness, and reducing training and skill maintenance times and expense. Support of AGATE will be realized through participation in multiple working groups, with each of these activities constituting a project as follows: (4.1) primary flight displays; (4.2) primary flight controls; (4.3) multi-function displays (weather /traffic); (4.4) navigation displays; and (4.5) interface devices. A manifestation of advanced-technology display systems is the "glass cockpit"; the extensive use of CRT's to present multi-function graphical displays to the pilot. The present plan for these tasks is that CAMI will participate with the AGATE flight systems work group in the examination of candidate display formats and control-interface configurations. CAMI's rapid prototyping capability and ability to export candidate designs to AGARS for in-flight evaluation will be employed.

Task 5: Cockpit Display of Data-Linked Information

According to the GA Weather JSAT Final Report (1999), of fatal, GA weather accidents, a large percentage are caused by inadvertent flight into IMC. That report recommended several interventions aimed at reducing the rate of fatal, GA weather accidents, including the introduction of graphical weather information products, the improvement of the current FSS system (e.g., equipment and weather briefings), and improving DUATS. It is clear that future cockpit systems will have access to multiple and varied weather products, and discussions and standards writing are taking place to help define the design and use of these products. Although evaluations of specific parameters of graphical weather information products (e.g., amount of image compression) have been completed, the effect of these products on pilot comprehension, decision-making, and flight performance is unclear. In addition, there have been no systematic attempts to evaluate existing pre-flight weather products (e.g., DUATS, FSS briefing). Is the information contained in some products more difficult to comprehend and/or understand due to formatting, do such products adequately support strategic and/or tactical weather decision making, and does interpretation of information in graphical weather products differ significantly from that in text-based products? This task will provide pilot performance data that addresses such questions. A simulation protocol will be developed to systematically test and evaluate GA pilots' use of pre-flight weather information contained in several, currently available formats. The protocol also will evaluate formats and procedures used to provide in-flight weather briefings to GA pilots. Measures of pilot comprehension, decision-making, and performance will be included within the protocol. A technical report will include a complete analysis of empirical data and provide recommendations for improving formats and procedures used to obtain pre-flight and in-flight weather information. Recommendations for disseminating graphical weather information to the cockpit will be sensitive to weather products and services currently being developed for the FAA Flight Information Services (FIS) program.

14. Intended End Products/Deliverables:

Efforts on this ARR will result in products which will be delivered through such media as advisory circulars (AC's); DOT/FAA/CAMI informational pamphlets distributed to the GA community; educational materials provided to FAA safety counselors for distribution and presentation; guidelines to AVR for certification and rule making; equipment design specifications provided to GA equipment manufacturers (most notably AGATE industry partners); general human engineering guidelines for the design and integration of GA cockpit instrumentation; and so forth. Results of scientific studies will be documented in technical reports and memoranda, reported to sponsors at project review meetings, with a selected number being presented at professional meetings and submitted for publication in the scientific literature.

15. Schedule/Milestones:

Task 1: Pilot visual performance with integrated Primary Flight Displays (PFDs)	
1.1 Experimental design completed; protocols developed, analyses specified	
1.2 Simulation scenarios designed; preliminary experiments conducted	ongoing
1.4 Full-mission simulations conducted in AGARS	
1.5 Data reduced/statistical analyses completed; draft report completed	
Task 2: Multi-function Display (MFD) guidelines, standards, and evaluation procedures	
2.1 Compile and edit annotated bibliography	FY99 Q2 Completed
2.2 Compile and edit guidelines summary	FY99 Q4 Completed
2.3 Reconfigure AGARS (hardware)	FY99 Q1 Completed
2.4 Install vendor-provided software and interface with AGARS	FY00 Q1
2.5 Collect pretest data	FY00 Q1
2.6 Collect/analyze primary data	FY00 Q2
2.7 Report findings, recommendations	FY00 Q3
Task 3: Cockpit Auditory and Visual Alarms in a multi-task environment	
3.1 Design Study	FY00 Q1
3.2 Reconfigure AGARS (hardware/software)	FY00 Q2
3.3 Collect pretest data	FY00 Q2
3.4 Collect/analyze primary flight data	FY00 Q3
3.5 Report findings, recommendations	FY00 Q4
Task 4: Advanced controls for GA aircraft: AGATE/SATS	
4.1 Design and evaluation of inputs to primary flight displays	Ongoing
4.2 Design support of pilot control/display interface devices	
Task 5: Cockpit Display of Data-Linked Information	
5.1 Design Study	FY99 Q1Completed
5.2 Reconfigure BGARS; develop supporting displays	FY99 Q2Completed
5.3 Develop simulation software	FY99 Q4Completed
5.4 Collect/analyze data	FY00 Q2
5.5 Report findings; make recommendations	FY00 Q3

16. Procurement Strategy/Acquisition Approach/Technology Transfer:

Technology transfer to the general aviation equipment community will be accomplished through such organizations as GAMA, SAMA, AOPA, through the AGATE, and through circulars and other media to the GA pilot community. It is anticipated that additional hardware/software support will be required to upgrade AGARS. Procurements will support the AGATE program and plans are to upgrade the device to support other aero model configurations and external avionics devices at an estimated cost of $85K.

17. Justification/History:
NTSB civil aviation accident data for 1998 indicate that of the total of 2040 accidents (1995: 2,188), 1,907 or 93% were associated with general aviation (1995: 94%). Of the total number of accidents, 377 were fatal (1995: 438) with general aviation accounting for 361 or 96% (1995: 93%). Total fatalities for 1998 were 663 (1995: 961) with 621 or 94% attributable to general aviation (1995: 76%). Note that general aviation includes all aviation operations with the exception of air carrier and the military. (Information was taken from the NTSB Annual Review of Aircraft Accident Data, 1998 Preliminary Data.) General aviation, due to its relatively high accident and fatality rates, offers a potentially high return on investment of R&D resources because of the larger potential payoff in increased aviation safety from interventions that serve to reduce those rates.

It has been estimated that over 80% of the accidents noted above within the general aviation community can be attributed to some form of pilot error. General aviation pilot "errors" may be precipitated by any number of causal factors including inappropriate decision-making, poor judgment, inappropriate attitudes toward flying, lack of the necessary skill level required for a particular set of flying conditions, or lack of knowledge of weather, procedures, rules, or regulations. Such "errors" could also be due to impairment induced by fatigue, drugs, alcohol, stress, hypoxia, preoccupation, or other stressors. In addition to those potential causal factors, general aviation accidents and incidents can also be attributed to confusing navigational charts, poorly conceived airspace restrictions, lack of standardization between aircraft, poorly designed cockpit interfaces including controls and displays, confusing avionics input and output entries, and new technology to which the general aviation pilot must adapt. This ARR is dedicated to developing and testing interventions that will serve to reduce the root causes of general aviation pilot "errors" and thereby achieve a reduction of general aviation accidents and incidents. Some of these interventions will arise from the application of emerging technology through AGATE. Supporting justification for this project area also can be found in Public Law 100-591, the Aviation Safety Research Act of 1988, and the Federal Air Surgeon's Annual Program Guidance Policy Statement, 1992-1993 which supports research on pilot impact of recent changes in the cockpit environment and assessment of pilot attributes required to perform safety in current and future advanced cockpits. The National Plan for Civil Aviation Human Factors also stresses the urgency of fully integrated human factors research. These activities are also in response to the report of the Gore Commission and its call for interventions to reduce the aircraft accident rate, and are in support of the Safe Flight 2000 initiative.

18. Issues:
Human subjects will be used and, as such, each will be informed of the tasks to be required. No drugs or alcohol are to be used in the research. A description of the research protocol and subject consent form will be submitted to the FAA Institutional Review Board for approval. Support will also be provided for the "ATS concept of operations for the National airspace System in 2005."

19. Transition Strategy:
Transition of R&D findings from the ARR will be accomplished through existing FAA structures within the Flight Standards organization, GA safety counselors, and Aircraft Certification. Other transitions will be accomplished through representation at general aviation industry expositions and technical meetings and through the NASA AGATE, SATS, and AWIN programs. Transition will also be facilitated by continued coordination with the General Aviation Coalition and participation with the four working groups currently operating within that organization.

20. Impact of Funding Deferral:
Deferred funding of this project would likely result in significant delays in understanding the contribution of the specified avionics devices and situations to aircraft accidents and incidents. This would translate into a continuance of general aviation accidents at an unabated rate (1,907in 1998), many of which involve fatalities (361 in 1998), and the accompanying loss of life and property damage. One can not discount the indirect costs to society related to subsequent insurance claims, lost wages and productivity, and litigation as well as investigatory costs to the agency. Deferral would also significantly restrict or prohibit participation in the AGATE and SATS programs and compromise application of human factors standards and criteria to the developing avionics and control systems.

21. R&D Teaming Arrangements:
The HFRL will collaborate with other federal laboratories and university research centers important to the accomplishment of stated research objectives. In particular, coordination will be maintained with the NASA general aviation program currently being managed at NASA Langley. Continued coordination and participation will be maintained with the General Aviation Coalition composed of FAA-AFS, AOPA, GAMA, SAMA, EAA, and NBAA. The goals of this plan are shared by this ARR and include aviation safety, product innovation and competitiveness, air facilities capacity and access, and affordability of innovations by the GA pilot community. Additional support for tasks will be obtained through grants to the New Mexico State University, the University of Illinois Aviation Research Laboratory, and other institutions. Teaming with CAMI's Aircraft Accident Research Team (AAM-600) will be pursued where appropriate.

22. Special Facility Requirements:
The General Aviation Flight Simulation Research Facility at CAMI including both AGARS and BGARS will be used in the performance of most experimental tasks.

23. Approvals (Signature Authority):	***Project Revalidation***	***Performing Organization***
______________________ Nancy Lane Special Assistant to the Director Aircraft Certification Service (AIR-3)	____________ Date	______________ William E. Collins, Ph.D. Director, FAA Civil Aeromedical Institute, AAM-3
______________________ Jon L. Jordan, M.D. Federal Air Surgeon, AAM-1	____________ Date	______________ Date